Experimental study of optical fibers influence on composite

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ABSTRACT

Bending strength and elasticity modulus of composite, with and without embedded optical fibers, were experimentally studied. Two kinds of laminates, which were denoted as group 1 and group 2, were fabricated from an orthogonal woven glass/epoxy prepreg. Since the normal stress value becomes the biggest at the surface of a beam, the optical fibers were embedded at the outmost layer and were all along the loading direction. Four types of materials, using each kind of laminated prepreg respectively, were manufactured. The embedded optical fibers for the 4 material types were 0, 10, 30 and 50 respectively. Three-point bending tests were carried out on the produced specimens to study the influence of embedded optical fiber on host composite. The experimental results indicated that the materials in group 2 were more sensitive to the embedded optical fibers.

Keywords: smart composite, optical fiber, bending performance

1. INTRODUCTION

Individual fibers or fiber networks are often used in smart structures for real time structural health monitoring[1-2]. However, despite of the small physical size of the optical fiber compared with the host composite structure, the diameter of the optical fiber (250μm) is comparably larger than that of reinforcing fibers (~7μm). The mismatch in dimension will inevitably lead to stress concentrations and possibly reduce the mechanical properties of the composites. Coupling between composite and the embedded sensors has been research consideration for a long time[3-4.]

Embedment of optical fiber inside a composite may decrease the sensitivity of a sensor. Yuan L. etc.[5] and Li etc. [6] studied the strain transferring of embedded optical fiber strain sensors. Although the mechanical models were different in their studies, they found that the longitudinal stress and strain distribution in the optical fiber sensor were different from the host material.

Kalamkarov and Fitzgerald[7] studied the mechanical performance of fiber reinforced polymer tendon embedded with Fabry-Perot fiber-optic sensors. The embedded experimented sensor readings agreed very well with theoretical value. They pointed that the performance of the embedded sensors was not affected by temperatures changes.

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Lee etc.[8] investigated the effect of embedded optical fiber on the mechanical characteristics of glass fiber/epoxy composite laminates. Unidirectional and cross-ply specimens with different numbers of embedded optical fiber were manufactured. The laminates were tested under static tensile and low cycle fatigue load. The test results showed that the embedded optical fibers had no significant effect on the static properties of composite specimens. However, the cross-ply type with the most quantity of optical fiber displayed a small different in Poisson's ration compared with others. Nevertheless, significant reduction of fatigue life composite structures with embedded optical fibers was observed.

Finite element techniques were used to analyze the mechanical character of carbon fiber reinforced laminate embedded with optical fiber by Benchekchou and Ferguson[9]. Simulation revealed that high stress concentration was seen in the embedded optical fiber and layers surrounding it. However the embedded optical fiber did not significant change the stress distribution at other position. Fatigue experiments showed that the location of the embedded fiber was important, and could alter the fatigue behavior of the specimen.

Surgeon and Wevers[10] carried out static and dynamic tests on a T400/epoxy composite with embedded optical fibers. The composite lay-up used was $[0/45/-45/90]_s$. The optical fibers were positioned in different layers, all along 90°, in the quasi-isotropic laminate. They pointed out that only a minor influence of the optical fiber was noticed during tensile tests. This happened only in the case as the optical fibers were embedded in the 0-layers. However, degradations in bending strength up to 51% were observed. Different configurations with optical fiber embedded in different layer showed different influence on the mechanical characters of the result structures. Among the configurations, two showed a minimal influence on the mechanical properties: incorporation in the 45/-45 interface and incorporation in the 90/90 interface.

Ling HY etc. [11] studied the influences of optical fiber embedment on the fracture behaviors of composite laminates. They simulated delamination inside composite laminates, and the effects of embedded optical fiber on mode II fracture behaviors of woven composite laminates were investigated theoretically and experimentally. They have addressed that the embedment of the optical fiber would cause a reduction of maximum load for which the composite specimen can sustain before fracture occurred. The mode II energy release rate of the specimen with embedded optical fiber was found to be lower than that without the embedded optical fiber.

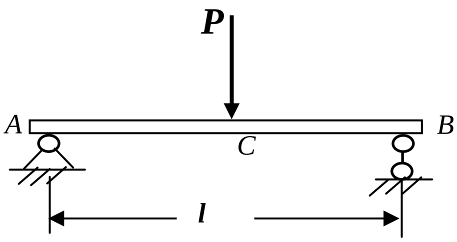
The paper reports on the three-point bending properties of glass fiber reinforced polymer (GFRP) with different quantity of embedded optical fibers. The optical fibers were incorporation in the outset layers, and normal to loading direction.

2. THEORETICAL ANALYSIS

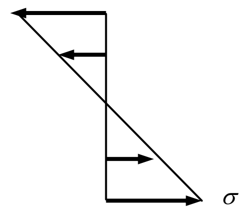
As a beam is flexure at middle part (shown in Fig.1a.), the middle section is subject to the maximum load. Fig.1b shows the normal stress distribution of a section. The normal stress distributes linear along the height. The value of the normal stress reaches a peak at the surface of the beam. Therefore, the bending strength of a sample can be calculated by the below equation.

$$\sigma = \frac{3P_b l}{2bh^2} \tag{1}$$

Hereby, P_b is the maximum load during sample brokering. b and h are width and thickness of the beam respectively.



(a) Three-ponit bending



(b) Normal stress along the height

Fig. 1. Sketch of experimental theory

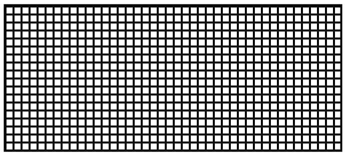
Usually, the vertical displacement increases linearly with applied load ΔP, or linear with $1/EI$ at the beginning of flexure. E is the modulus of material, and I denotes the inertia moment of a section. The value of modulus can obtain by experiment, and it can be calculated by the below equation.

$$E = \frac{\Delta P l^3}{4bh^3 \Delta f} \tag{2}$$

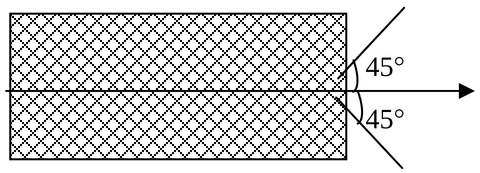
3. EXPERIMENTAL PROCEDURE

3.1 Experimental material

Laminates were produced by hand lay-up process from an orthogonal woven glass / epoxy prepreg. The prepreg was cut into two kinds, one with fibers in 0°and 90° (specimens fabricated were denoted as group 1), and the other with fibers at ±45° (specimens fabricated were denoted as group 2). Fig.2 showed the sketch of the two kinds cut prepreg. Samples were made from the different prepreg respectively. The prepreg stacks were laminated as 24-ply panels. Polyimide coated multimode optical fibers of 245μm, which consist of 62.5μm core and 125.2μm cladding, were used. The optical fibers were embedded between the first and second layers, counted from the bottom of the specimen. During the lamination process, optical fibers were embedded as evenly as possible in the outset layers and all normal to loading direction. Eight different types of plates were produced. The test samples had a length of 150mm, a width of 15mm and a thickness of 3mm. A manufactured plate was shown in Fig.3. Table 1describes the specimen configurations and the number of embedded optical fibers.



a. fibers at normal to centerline of the plate



b.fibers along 45° direction of the centerline

Fig. 2. Sketch of cut prepreg

Fig. 3. Prepared specimen

Table 1 Details of specimen configuration

Group	Material type	Prepreg type	Numbers of optical fiber
1	G00	0	0
	G01	0	10
	G03	0	30
	G05	0	50
2	Gx0	45	0
	Gx1	45	10
	Gx3	45	30
	Gx5	45	50

3.2 Experimental details

Three-point bending tests were carried out on the designed material types to study the mechanical influence. For each kind of the type, six specimens were prepared. The tests accomplished on Instron 5566 testing machine. Fig.4 is the test set-up. The span was set to 48mm. A displacement transducer was used to record the maximum vertical displacement.

Fig. 4. Experimental set-up

The load was applied with the displacement control mode at the rate of 1.6 mm/min. Data were collected by a computer data acquisition system automatically.

4. RESULTS AND DISCUSSIONS

4.1Strength study

When being bent, the specimens in group1 were broken gradually. The broken of the fiber can be heard during the tests. Bending strengths of the test pieces were shown in Table 2. The maximum experimental error was less than 10%.

Table 2. Test result for bending strength for group 1

Type	Bending strength (MPa)					
	Test1	Test2	Test3	Test4	Test5	Average
G00	430.4	382.5	431.7	450.6	409.4	420.9
G01	425.8	427.7	381.4	399.8	401.5	407.3
G03	369.8	403.1	401.9	421.6	396.7	398.6
G05	383.7	385.8	381.8	423.6	394.7	393.9

For clarity, the average bending strength of different material types was compared graphically in Fig.5. It can be observed that the bending strength decreased as the embedded optical fiber increased. The bending strength was about 3.2% less for G01 as compared to G00, which had no optical fiber embedded inside. The strength value kept decline for material type G03 and G05. The reductions were 5.3 % and 6.4 % for G03 and G05, respectively.

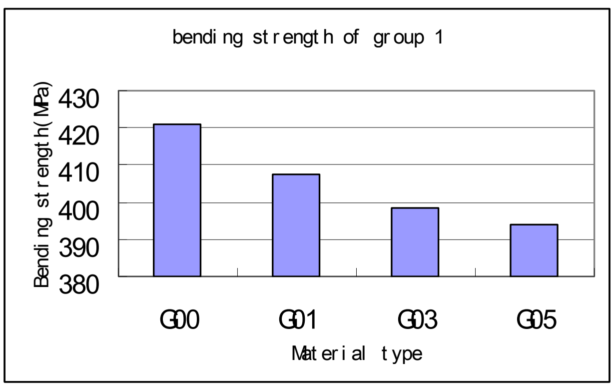
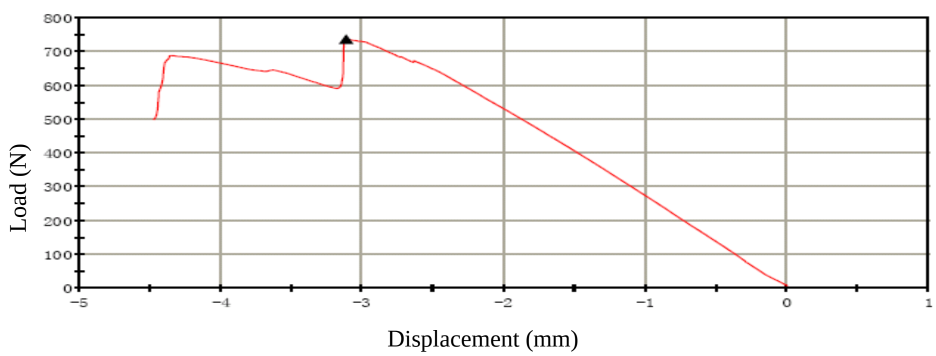
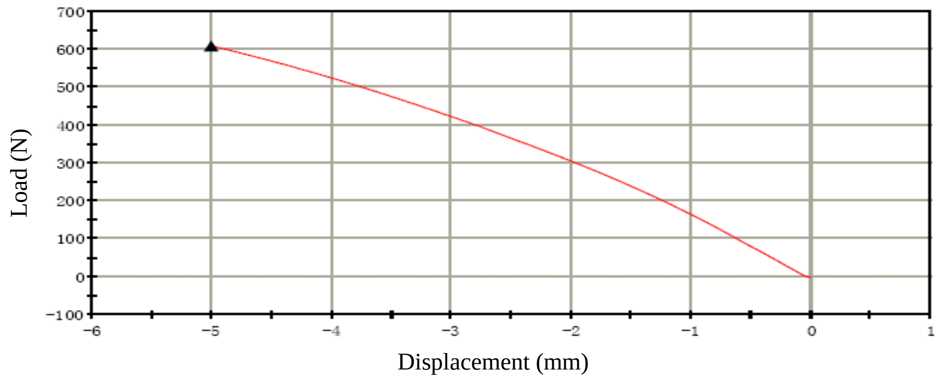


Fig. 5. Average bending strength comparison of group 1

However, the samples of group 2 exhibited better flexure. Nearly no fiber broken was observed during the tests. Fig.6 respectively showed the auto-recorded curves for one sample in group 1 and group 2.



(a) Bending curve of a specimen in group1



(b) Bending curve of a specimen in group 2

Fig. 6. Auto-recorded curve for different group

It was shown in Fig.6 that the loading force increased gradually for both samples in group 1 and group 2 at the beginning of the tests. However, the specimen of group 1 had a sharper climb. After maximum load, there was a fall in Fig.6a. The load bounced back and fallen again till the vertical displacement was almost equal to what the displacement sensor allowed. Every time as there was a load fall, there was fiber broken inside the testing laminate. In Fig.6b, the load remained grow moderately. No load fallen was observed. No fiber broken was found during the tests even as the punch arrived at the bottom.

The possible reason was that the reinforced glass fibers were subjected to not only bending but also torsion in the materials of group 2. The glass fibers were orthogonal. The applied load was along 45 direction of the glass fiber. Therefore, when the laminate was subjected to bending, the tensile stress on the glass fibers was weakened. This caused good flexure for material types of group 2.

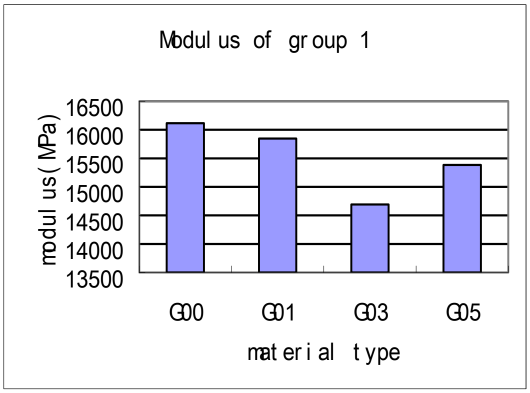
4.2 Modulus study

During tests, the values of load and the corresponding vertical displacement were auto-recorded. Graphs of the load against displacement of various cases were studied. The beginning part was linear. Slope of the linear curve was calculated for each specimen. By substituting the calculated rate into Eq.2, the modulus of every sample can be found.

Fig.7 exhibited the elasticity modulus of different material types. As shown in Fig.7a, the modulus of the tested samples was declined as the embedded optical fibers increased firstly. The materials in G03 had a smallest modulus value, 8.9% off compared with the reference material G00. The materials in G05, with the most optical fibers embedded, showed a rise in modulus. However the increasing degree was less than 5%.

The types of group 2 were more susceptible to the number of embedded optical fibers. The material types Gx1 and Gx3 exhibited a three-point bending modulus that was significant higher than that of the reference material Gx0. The increase in modulus was approximately 33.3%. The material type Gx5 showed a minor increase in the modulus. A possible reason was that the optical fibers, which were embedded along the bending load direction, sustained partial of the load. The modulus of the used optical fiber was about 72GPa, which was significant higher that the host material. However, as the embedded optical fibers were 50, the first layer and the second layer of the composite were almost delaminated. Therefore, the growth in modulus was depressed.

The type Gx0 exhibited a three-point bending modulus that was lower than the type G00. A modulus reduction of 41% was observed. The explanation for this was once again the distortion inside the woven glass fibers for material types of group 2.



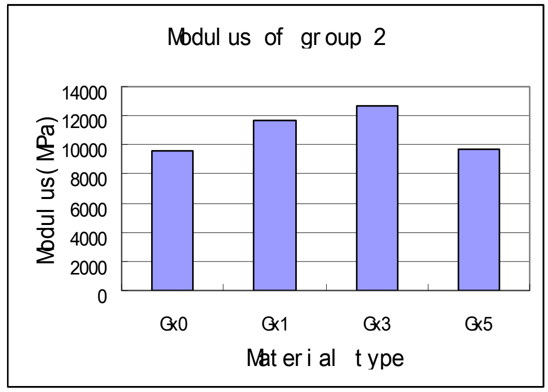


Fig. 7. Bar chart of averaged elasticity modulus for different material

5. CONCLUSIONS

Based on the experimental results reported herein, some conclusion can be obtained.

If no glass fibers reinforced along loading direction, the laminate was more easily deformed when it underwent bending.

The sheets became increasingly rigid as the embedded optical fiber grew. However, more embedded optical fiber doesn't mean more stiffness, since too much optical fiber may decompose the laminate.

The flexure strength and modulus were not so easily influenced if the optical fibers were embedded along reinforced direction for the studied composite herein.

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